

# ORION FLIGHT TEST-1 THERMAL PROTECTION SYSTEM INSTRUMENTATION

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The Orion Crew Exploration Vehicle (CEV) was originally under development to provide crew transport to the International Space Station after the retirement of the Space Shuttle, and to provide a means for the eventual return of astronauts to the Moon. With the current changes in the future direction of the United States' human exploration programs, the focus of the Orion project has shifted to the project's first orbital flight test, designated Orion Flight Test 1 (OFT-1). The OFT-1 is currently planned for launch in July 2013 and will demonstrate the Orion vehicle's capability for performing missions in low Earth orbit (LEO), as well as extensibility beyond LEO for select, critical areas.

Among the key flight test objectives are those related to validation of the re-entry aerodynamic and aerothermal environments, and the performance of the thermal protection system (TPS) when exposed to these environments. A specific flight test trajectory has been selected to provide a high energy entry beyond that which would be experienced during a typical low Earth orbit return, given the constraints imposed by the possible launch vehicles. This trajectory resulted from a trade study that considered the relative benefit of conflicting objectives from multiple subsystems, and sought to provide the maximum integrated benefit to the re-entry state-of-the-art. In particular, the trajectory was designed to provide: a significant, measureable radiative heat flux to the windward surface; data on boundary transition from laminar to turbulent flow; and data on catalytic heating overshoot on non-ablating TPS.

In order to obtain the necessary flight test data during OFT-1, the vehicle will need to have an adequate quantity of instrumentation. A collection of instrumentation is being developed for integration in the OFT-1 TPS. In part, this instrumentation builds upon the work performed for the Mars Science Laboratory Entry, Descent and Landing Instrument (MEDLI) suite to instrument the OFT-1 ablative heat shield. The MEDLI integrated sensor plugs and pressure sensors will be adapted for compatibility with the Orion TPS design. The sensor plugs will provide in-depth temperature data to support aerothermal and TPS model correlation, and the pressure sensors will provide a flush air data system for validation of the entry and descent aerodynamic environments. In addition, a radiometer design will be matured to measure the radiative component of the reentry heating at two locations on the heat shield. For the back shell, surface thermocouple and pressure port designs will be developed and applied which build upon the heritage of the Space Shuttle Program for instrumentation of reusable surface insulation (RSI) tiles.

The quantity and location of the sensors has been determined to balance the needs of the reentry disciplines with the demands of the hardware development, manufacturing and integration. Measurements which provided low relative value and presented significant engineering development effort were, unfortunately, eliminated. The final TPS instrumentation has been optimized to target priority test objectives. The data obtained will serve to provide a better understanding of reentry environments for the Orion capsule design, reduce margins, and potentially reduce TPS mass or provide TPS extensibility for alternative missions.



# **Orion Flight Test-1 Thermal Protection System Instrumentation**

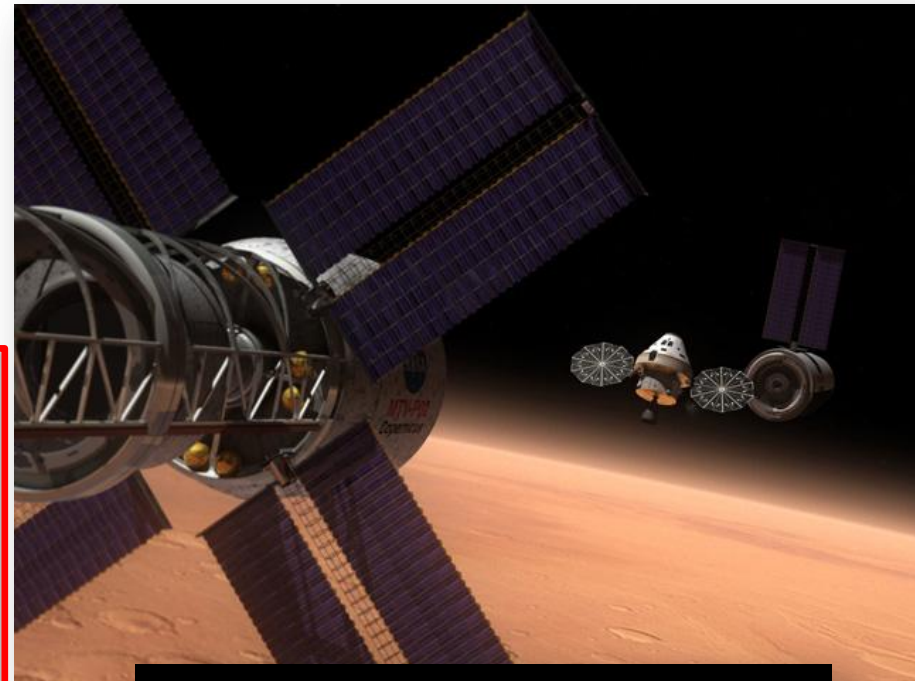
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NASA – Johnson Space Center**

**International Planetary Probe Workshop  
June 16, 2011**

# Since Last We Talked...



- Constellation Program has been cancelled
- Orion transitioning to the Multi-Purpose Crew Vehicle (MPCV)
  - Spacecraft to serve as the primary crew vehicle for missions beyond LEO
- Revised near-term focus on incremental spacecraft development with greater emphasis on orbital flight testing.
  - Targeting initial flight test to validate critical systems capability in 2013-2014 timeframe



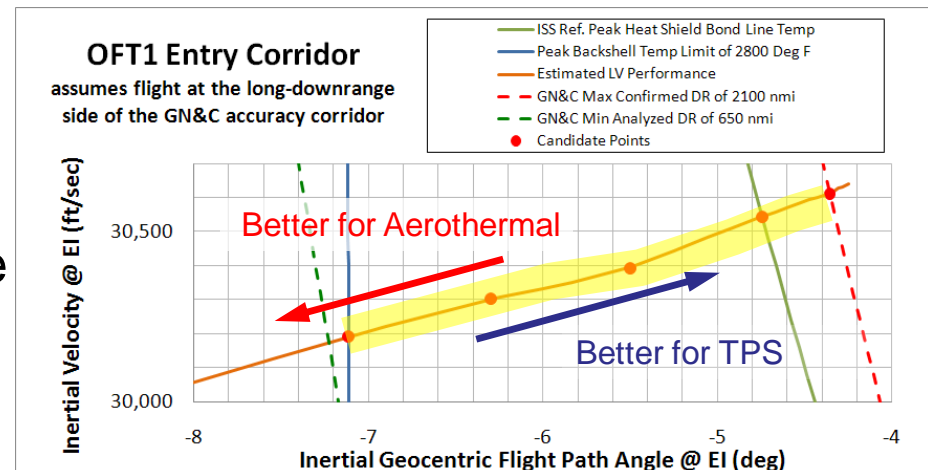
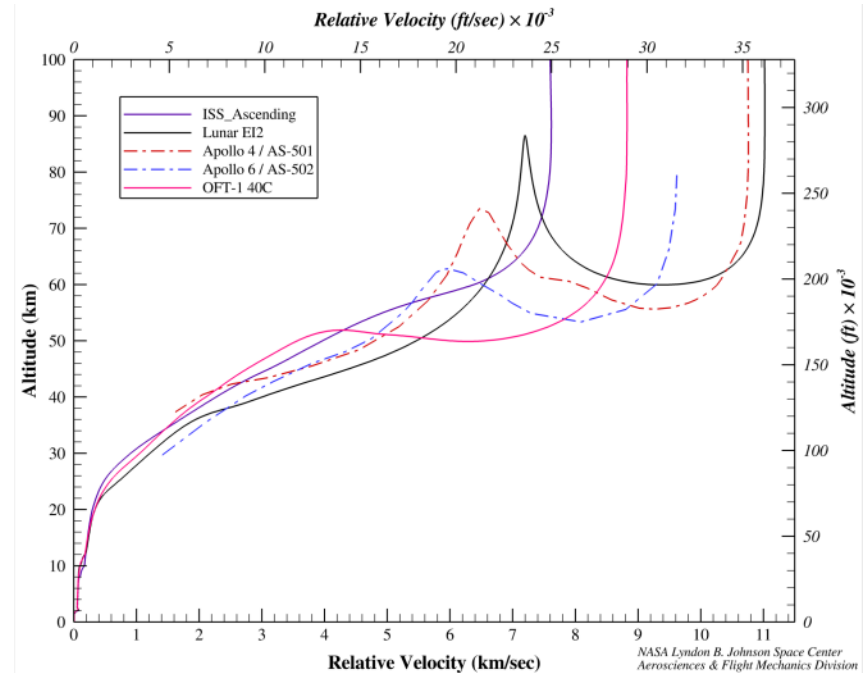
## Orion Flight Test #1 (OFT-1) Objectives:

- Demonstration of Critical Events for a crewed Orion mission
- Validate Orion Environments
- Demonstrate System/Subsystem Performance in integrated configurations and Orion 'Beyond-LEO' flight environments



# OFT-1 Entry Flight Design

- A “high energy” trajectory is preferred for OFT-1 in order to optimize aerothermal benefits in demonstrating Beyond-LEO capability
  - Steep flight path angle
  - Max entry interface velocity for expected launch vehicle & booster performance
  - Heat load, and thus TPS bondline, is not maximized
- Efforts to adjust GN&C performance in order to target TPS bondline temperatures consistent with an ISS mission
- High energy entry trajectory achieved with a 2 rev, high apogee orbit





# OFT1 TPS and Aeroscience FTOs



## Flight Test Objectives (all primary)

**OFT1.086** Determine CM TPS thermo-structural performance during re-entry environments. (Primary)

Rationale: Integrated TPS performance is un-testable on the ground due to the size of the system and the complexity of combined thermal and mechanical loads. The TPS is a DFMR subsystem relying on analytical verification for entry performance.

**OFT1.087** Determine CM TPS thermo-structural performance during launch, ascent, and on-orbit environments. (Primary)

**OFT1.041** Obtain data on TPS response due to CM RCS plume heating augmentation during re-entry. (Primary)

**OFT1.091** Determine heatshield and backshell aerothermodynamic environment during re-entry.

Rationale: Flight test data supports validation of transition, laminar and turbulent modeling of baseline OML for both equilibrium flow and non-equilibrium flow.

**OFT1.092** Determine catalytic overshoot environments. (Primary)

**OFT1.093** Determine RCS jet impingement aerothermodynamic environment during entry. (Primary)

**OFT1.095** Determine cavity aerothermodynamic environment during reentry.

**OFT1.101** Determine characteristics of MMOD cavity heating environment during entry. (Primary)

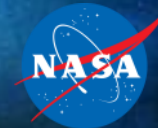
Rationale: Flight test data on a known intrusion into the thermal protection system supports validation of the cavity heating model which is the primary driver on tile thickness.

**OFT1.099** Determine the aerodynamic environment of the vehicle during all phases of nominal entry/descent. (Primary)

Rationale: Aerodynamic data is a critical element of the vehicle entry and descent flight environment.

**OFT1.026** Determine RCS jet effects on aerodynamics of CM during entry/descent. (Primary)

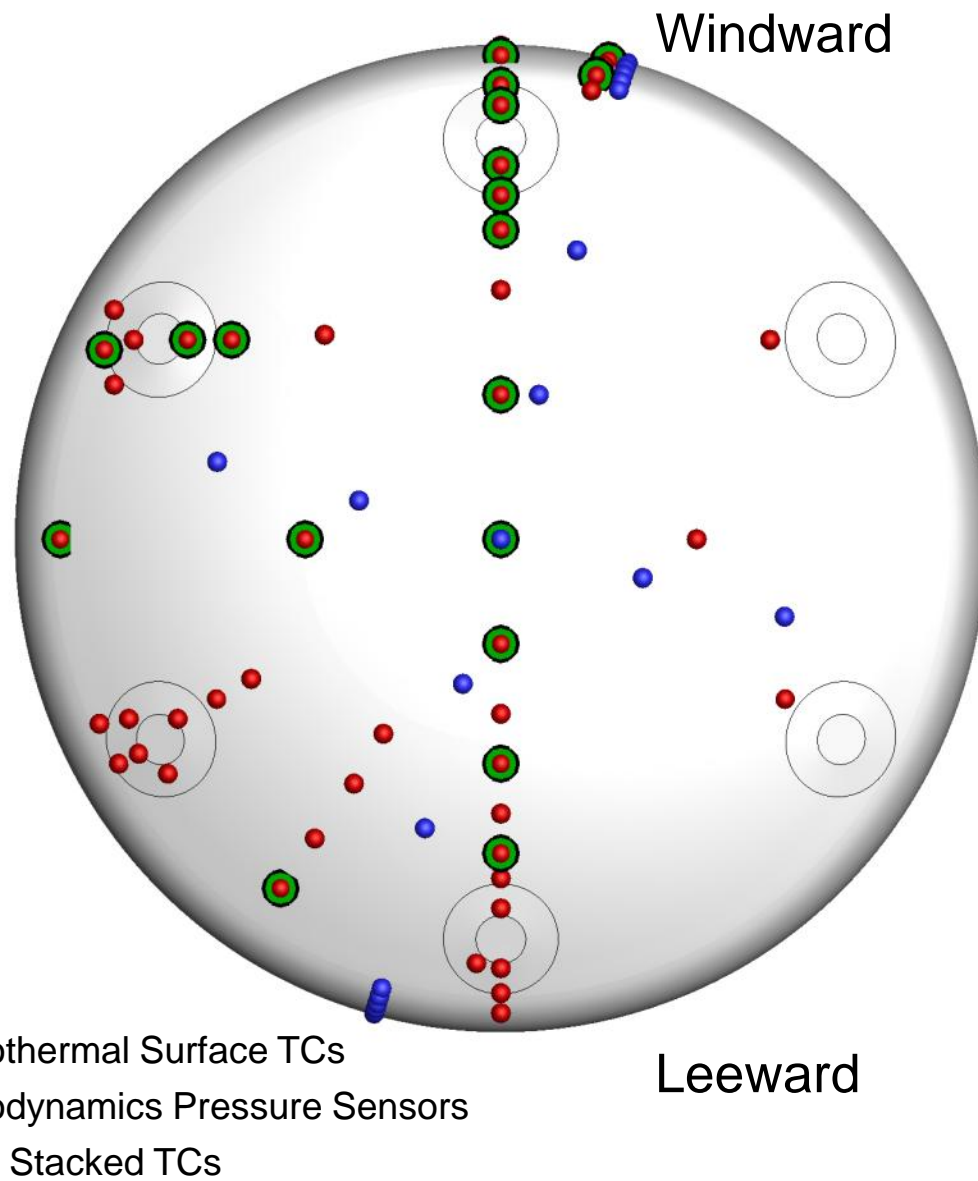
# Original Baseline Heatshield (HS) Developmental Flight Instrumentation ( DFI)



- As defined by Master Measurement List (MML)
- 31 Surface Thermocouple Plugs (Aerothermal)
- 25 Heatshield Pressure Ports (Aerodynamics)
- 19 Heatshield Thermal Plugs (TPS)

~~• 75 sensors total~~

- Total number reduced, based on consideration of:
  - Relative benefit
  - Integration Schedule
  - Integration Difficulty
  - Cost



- Aerothermal Surface TCs
- Aerodynamics Pressure Sensors
- TPS Stacked TCs

# Updated Heatshield Instrumentation

## ◆ 19 Heatshield Thermal Plugs

### ■ Symbol

1 surface TC

3 in-depth TCs,

1 bondline RTD (propose TC)

Isotherm follower

## ◆ 15 Heatshield Aerothermal Plugs

### ◆ Symbol

1 surface TC, 1 embedded

## ◆ 9 Heatshield Pressure Ports

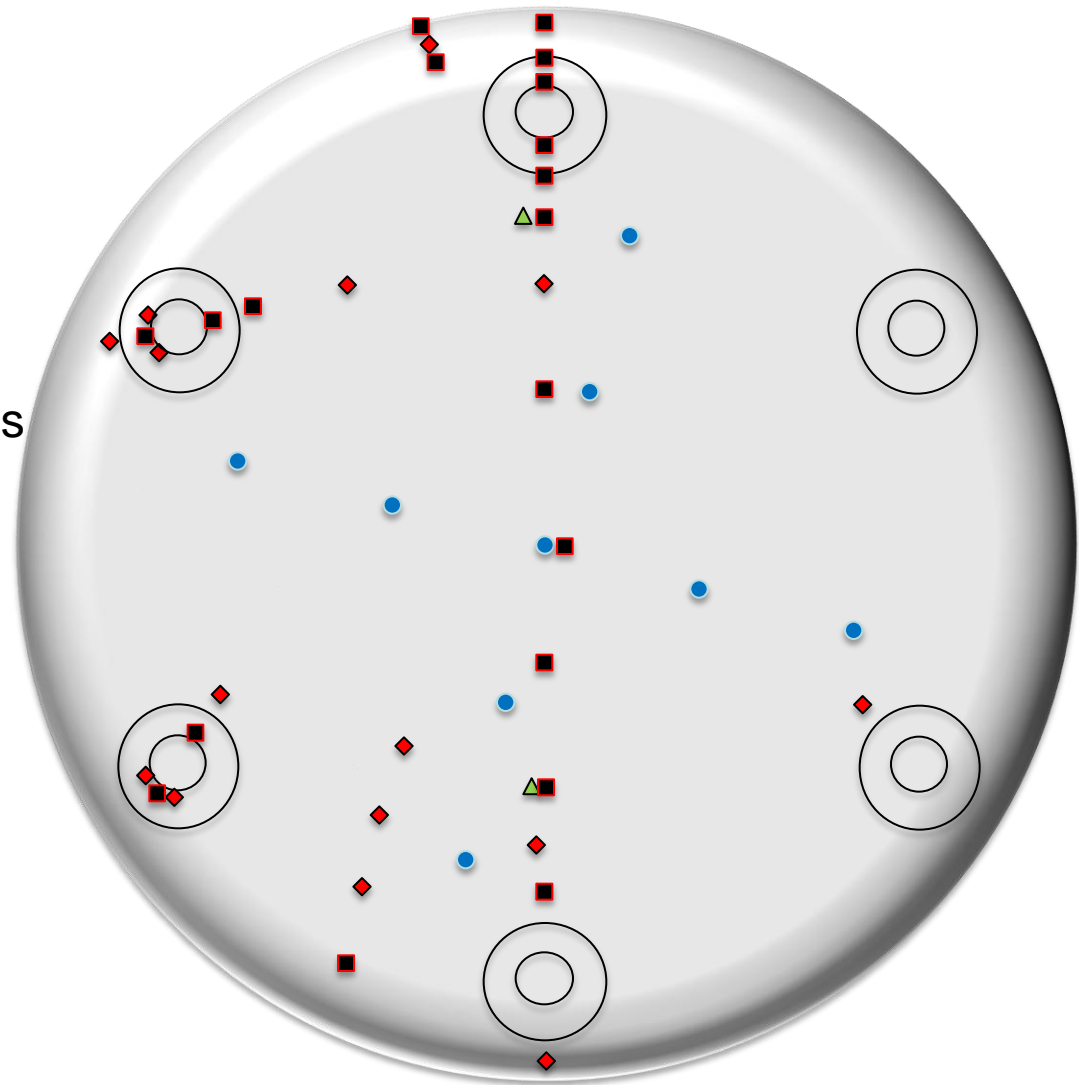
### ● Symbol

9 FADS and 7 shoulder

Pressure port and transducer

## ◆ 2 Radiometers

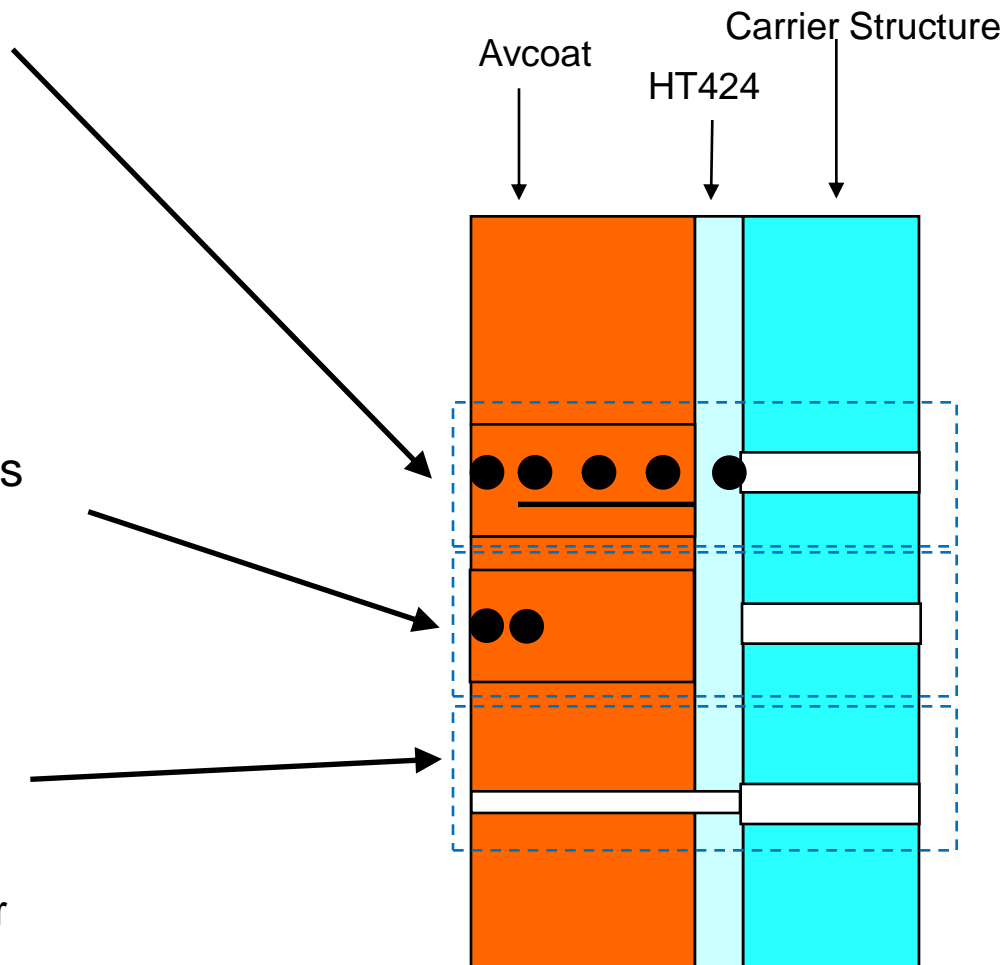
### ▲ Symbol



# Heatshield DFI Sensor Types



- Heatshield Thermal Plugs
  - 1 near-surface TC
  - 3 in-depth TCs,
  - 1 bondline TC
  - HEAT sensor
- Surface Thermocouple Plugs
  - 1 near-surface TC
  - 1 in-depth TC
- Heatshield Pressure Ports
  - Not a plug
  - Pressure port and transducer

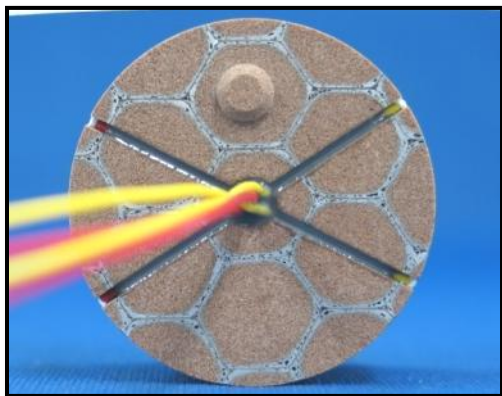




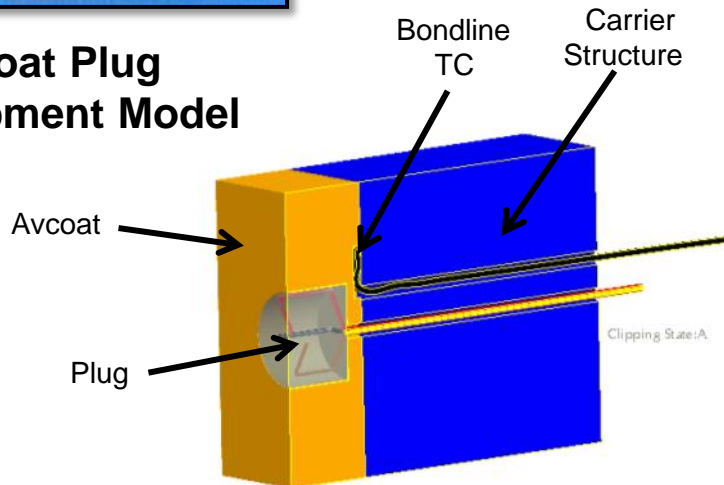
# Thermal Plug Concept



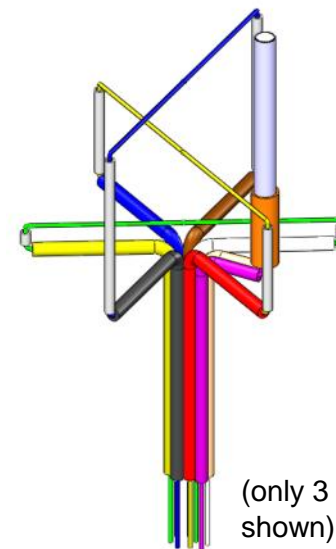
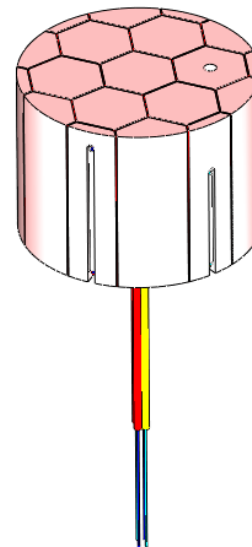
- Plug design derived from MSL Entry, Descent & Landing Instrumentation (MEDLI) Project
- Adapted for integration in Avcoat ablator



**Avcoat Plug Development Model**



## Final Orion HS DFI Plug Design:



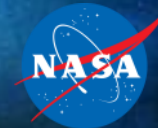
### Thermal Plug:

- 4 in-depth TCs
- TCs at the required depth
- Compatible adhesive
- Hollow aErothermal Ablation and Temperature (HEAT) sensor

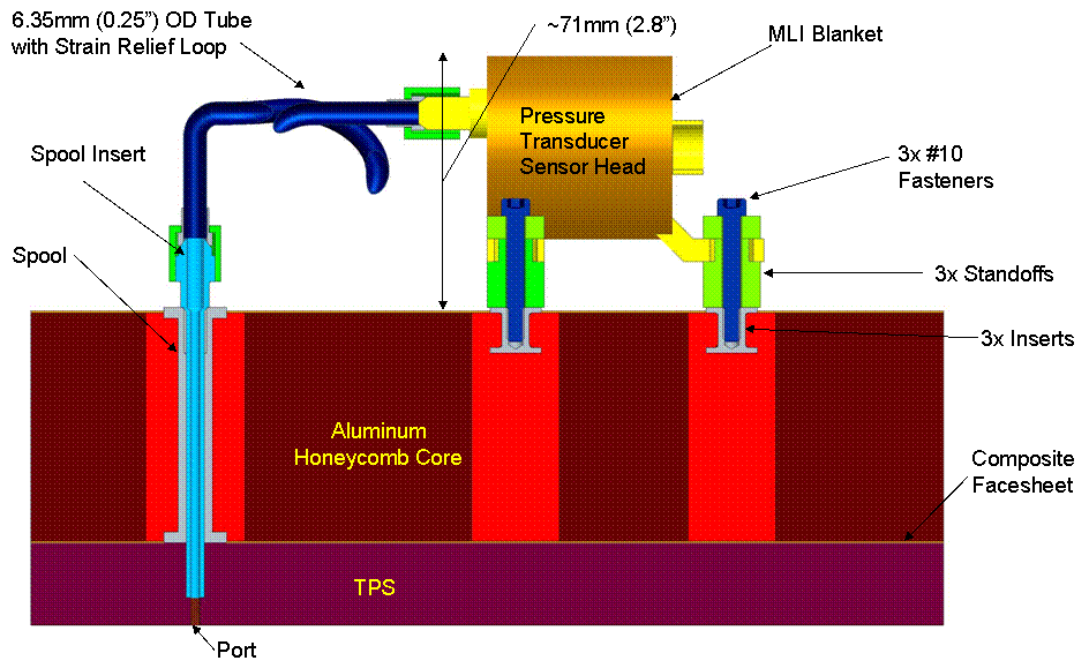
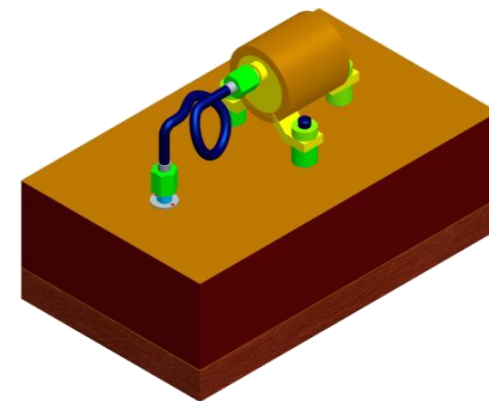
### Aerothermal Plug

- 2 in-depth TC's

# Pressure Port and Transducer Concept



- Leverage experience from past programs
- Utilize commercial off-the-shelf components, where applicable
- Confirm design compatible with Avcoat ablator

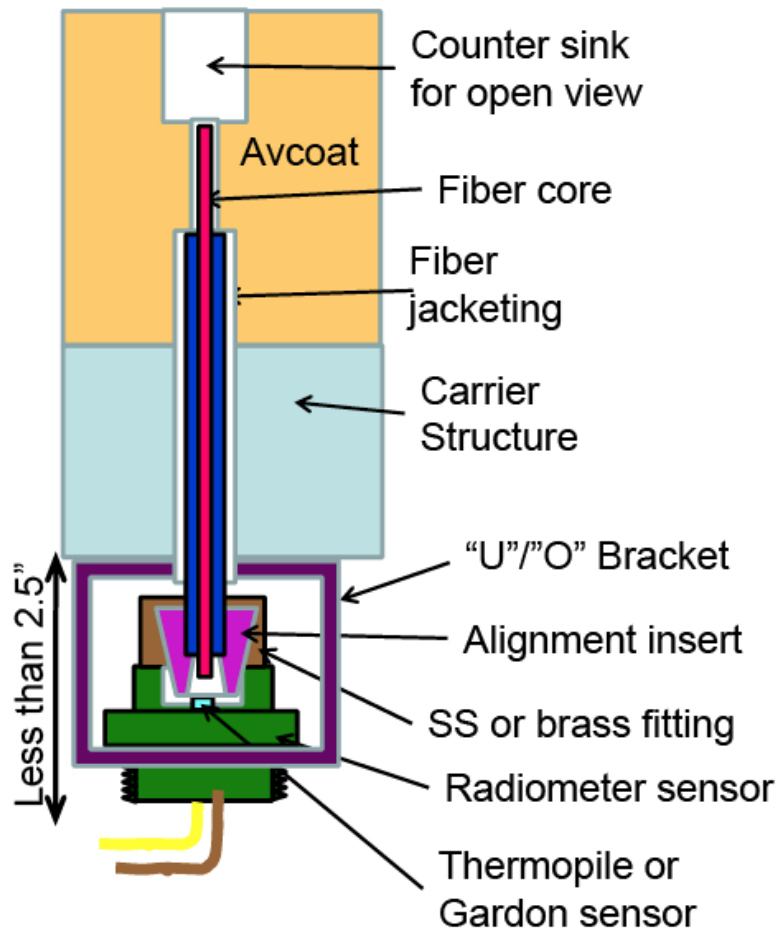


**Avcoat Arcjet Model With Various Size Simulated Pressure Ports**

# Radiometer Design



## Radiometer Design Concept

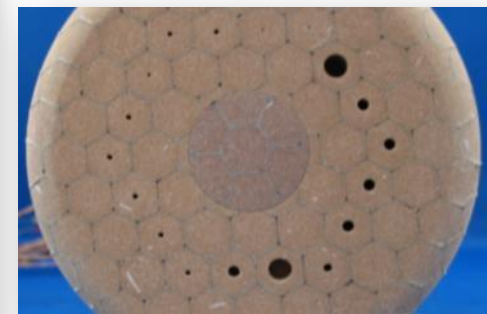


Objective: Measure radiative component of incident heat flux

- OFT-1 reentry heating is primarily convective, but radiative heating is significant
- For NEO missions, heating from shock layer radiation dominates both heat rate and heat load
- Radiative heating uncertainty/margin is larger than convective heating uncertainty/margin, and will have a large mass impact on a heatshield sized for a NEO mission



**Prior Development Model**







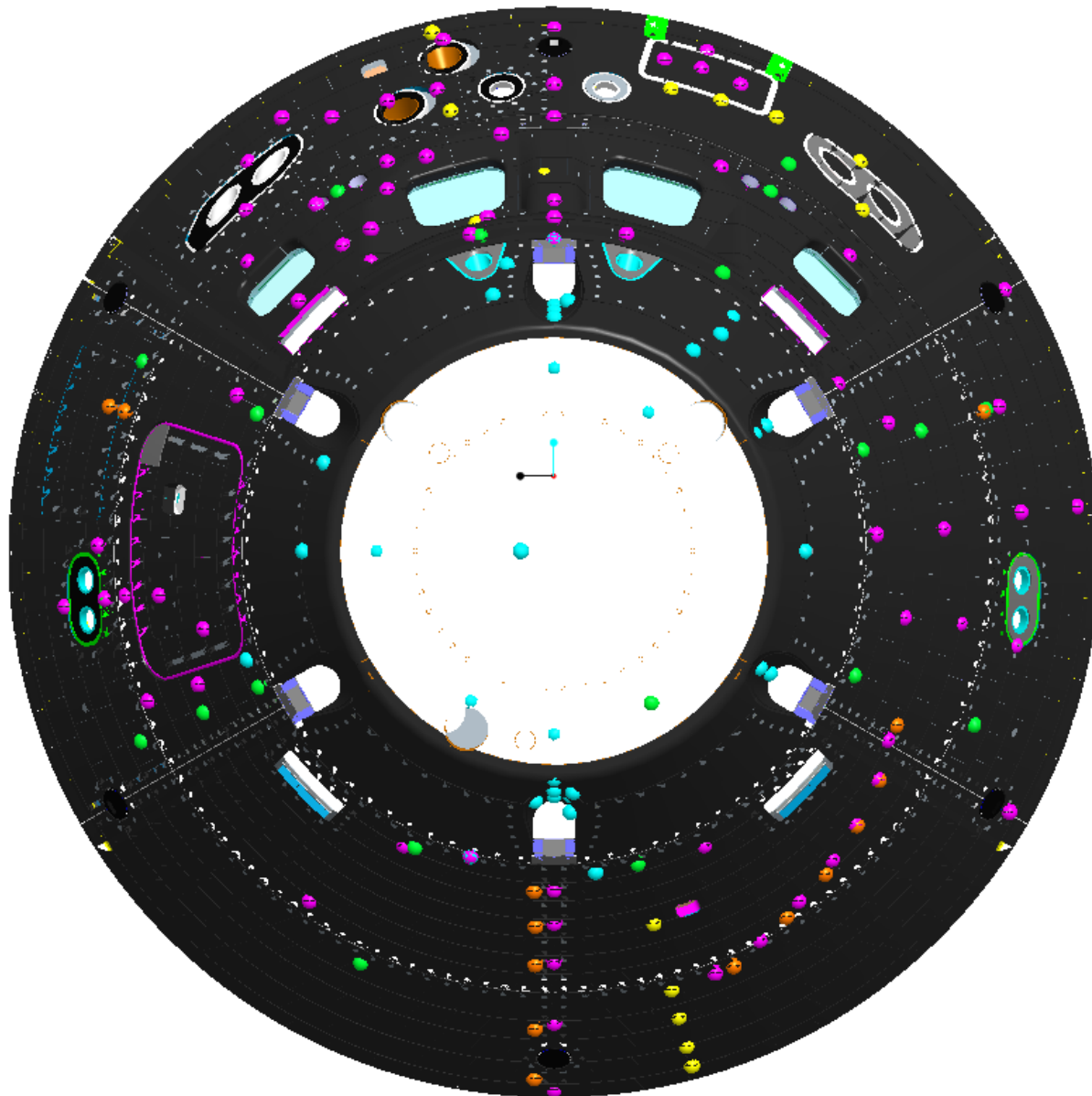
**Recent Avcoat Arcjet Model**



# Backshell DFI Sensor Locations



-  Pressure (33 total TBC)
- 
-  Temperature
  - 10 Plugs (YY in-depth tc's)
  - 115 surface tc's
-  Proposed relocations of temperature sensors

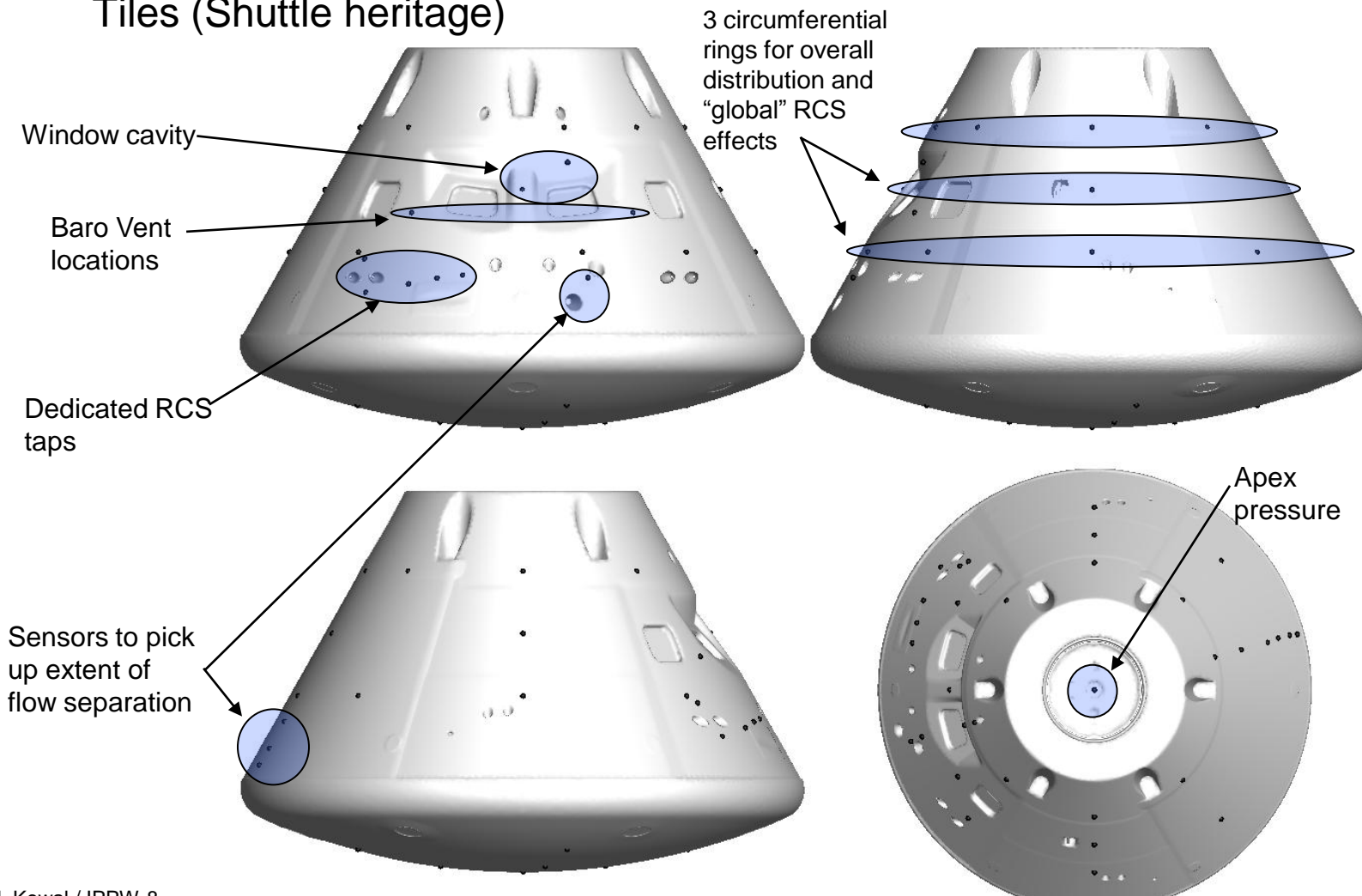




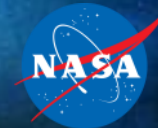
# Backshell Pressure Sensor Locations



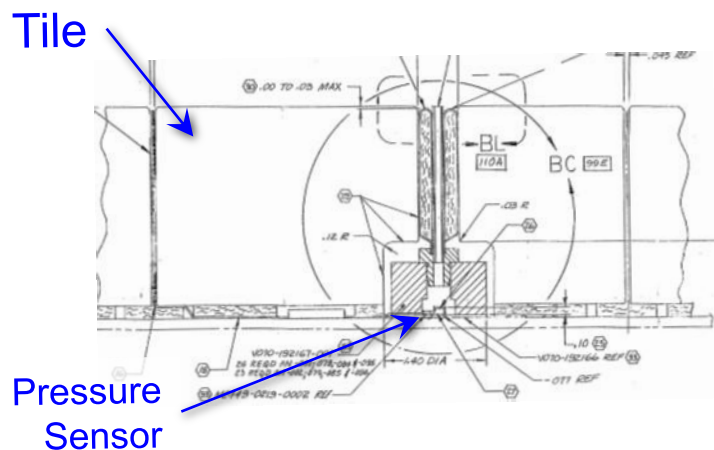
- 33 Pressure Sensors Total
  - Sensors embedded in ceramic TPS Tiles (Shuttle heritage)



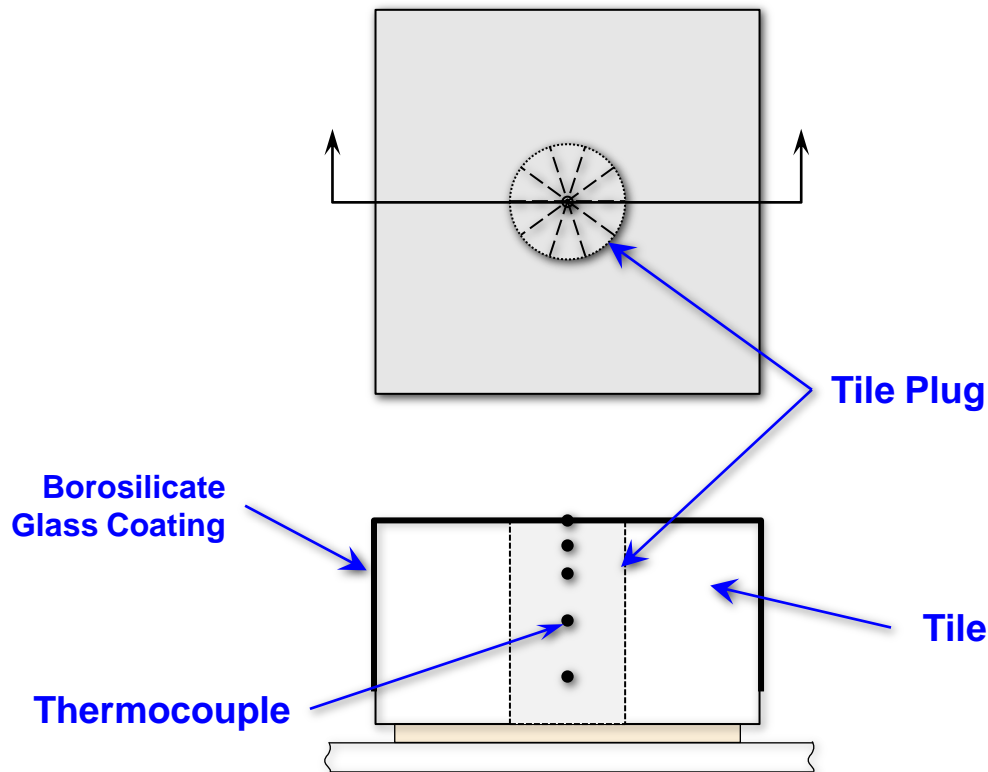
# Backshell Instrumentation



- Backshell instrumentation based on Shuttle design heritage

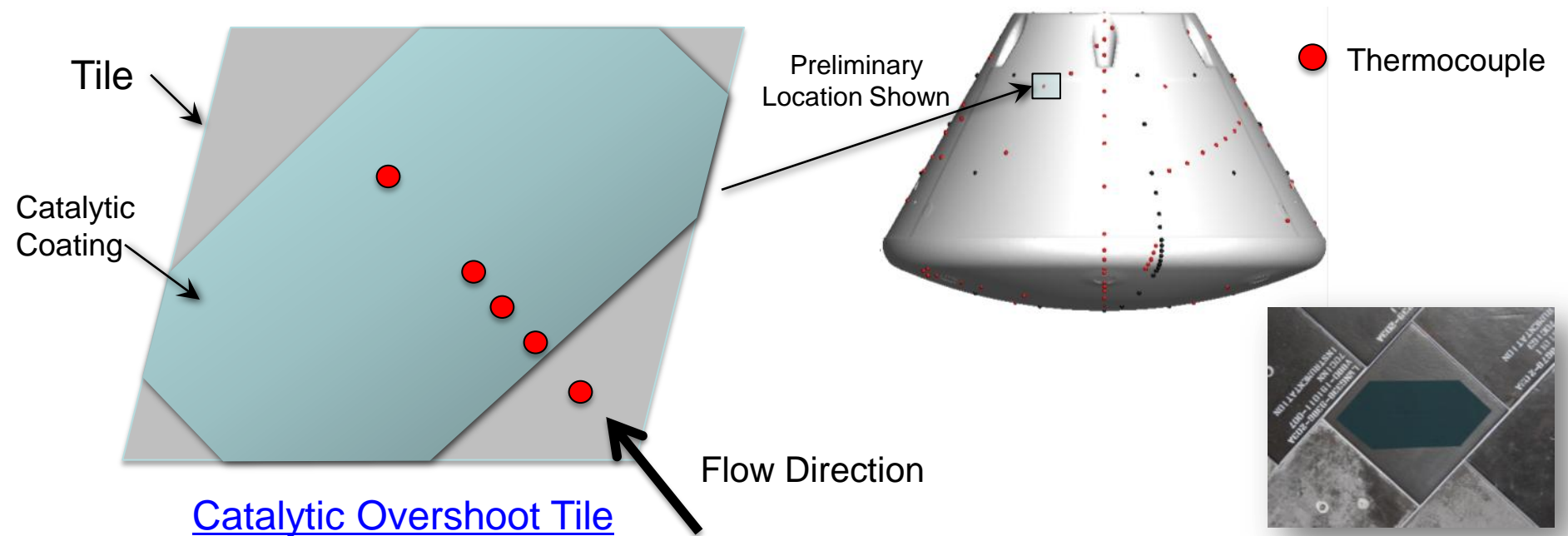


**Space Shuttle Tile  
Pressure Port Design**



**Space Shuttle Tile  
Thermocouple Installation  
(surface and in-depth tc's)**

# Catalytic Overshoot Experiment

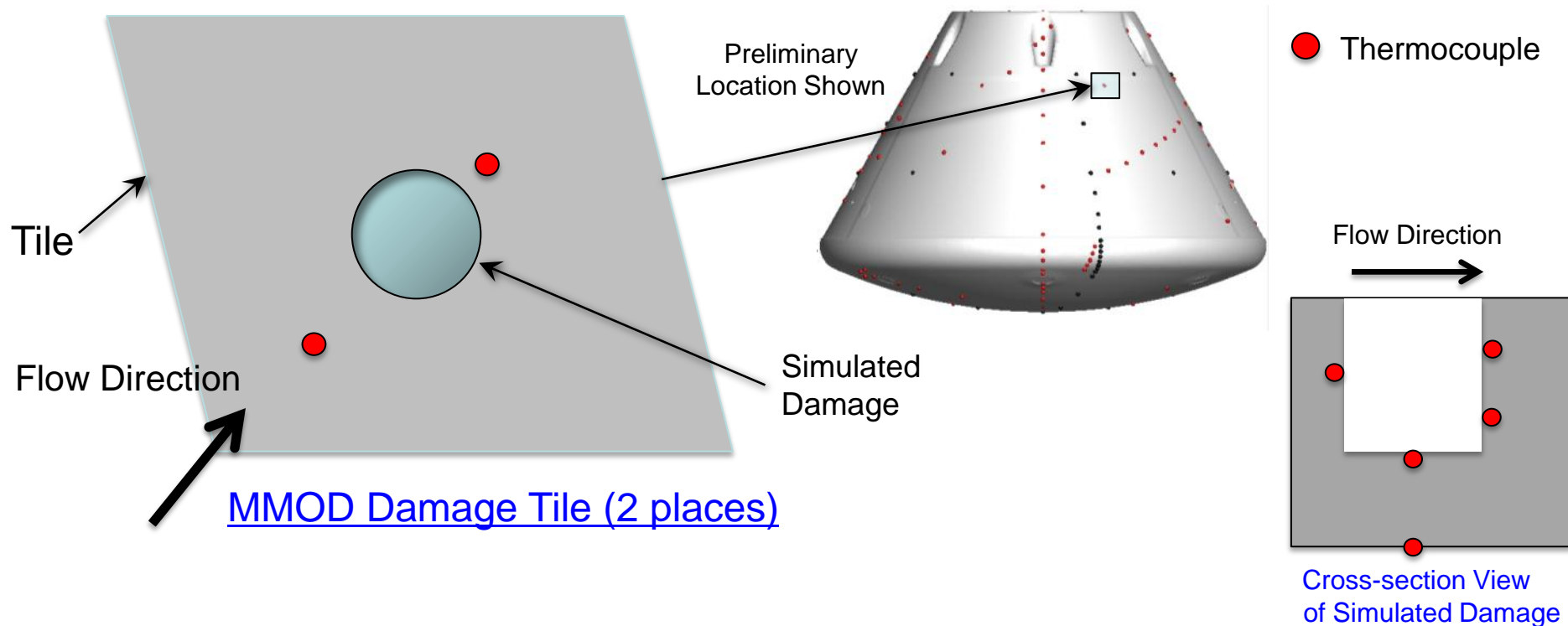


- **OFT-1 FTO: Determine catalytic overshoot environments**

- Determine aerothermal environment effects of isolated fully catalytic patches in non-catalytic acreage heatshield
- Atomic nitrogen and oxygen recombine on catalytic surfaces increasing the heating relative to non-catalytic surfaces
- Catalytic surfaces downstream of non-catalytic surfaces see an excess of atomic species
  - Amount of “catalytic overshoot” heating depends on the non-equilibrium chemical reaction rates that are poorly modeled
- This phenomenon cannot be captured appropriately on the ground
- OFT-1 provides unique opportunity to make measurements at greater than LEO reentry environment

**Duplicates experience from Space Shuttle Program experiment and provides additional unique data**

# MMOD Damage Experiment



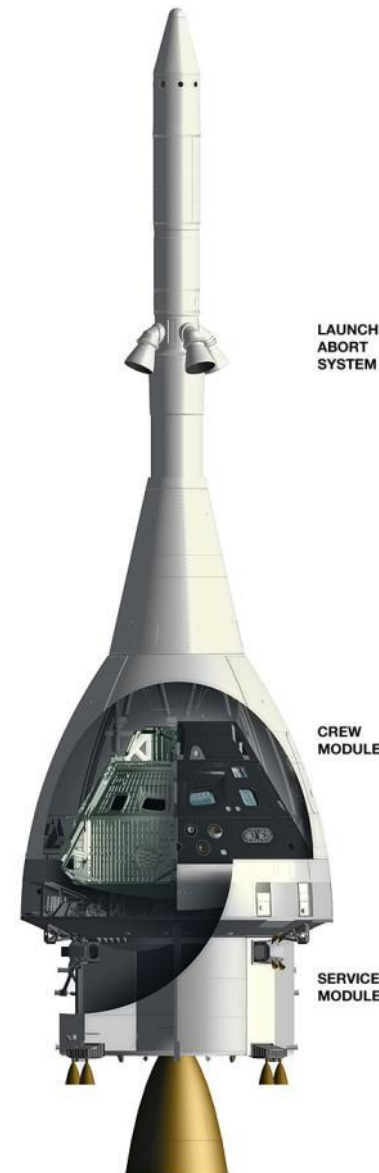
- OFT-1 FTO: Determine characteristics of MMOD cavity heating environment during re-entry
  - Determine aerothermal environments in cavities dimensionally similar to cavities resulting from MMOD impacts on orbit
  - Backshell tile thickness determined by MMOD requirements, and strongly coupled to aerothermal cavity heating environment
  - Current cavity heating model developed for shallow cavities (Shuttle heritage) and not for typical deep MMOD cavities



# The Path Forward



- The Orion MPCV is taking an incremental flight test approach to develop NASA's next crewed beyond-LEO spacecraft
- The first planned orbital flight test is Orion Flight Test-1 (OFT-1)
- The Orion Flight Test-1 crew module TPS will be instrumented with a variety of sensors to gather an unprecedented quantity and type of data during reentry to confirm beyond-LEO entry performance





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